Wire and Cable Characterization of Nb$_3$Sn Conductor with High Heat Capacity

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• Reduce magnet training by increasing Nb\textsubscript{3}Sn wire specific heat, i.e. replace some elements in wire with Gd\textsubscript{2}O\textsubscript{3} /Cu tubes.
• Worked with industry to produce wire prototypes
• Help achieve goals with Finite Element models, including:
  1. High-\(C_p\) tube location to optimize thermal efficiency
  2. High-\(C_p\) tube location for drawability/ fabricability
• Study model sensitivity
• Compare with data
• Conclusions


“Enhancing specific heat of Nb$_3$Sn conductors to improve stability and reduce training.”

Presented at CEC-ICMC 2019
Industry Produced Nb$_3$Sn Wires

**Gd$_2$O$_3$/ Cu tubes**

- Tin in Tube wire
- Internally and on Corners

Hypertech

X. Xu, P. Li, A. Zlobin and X. Peng,

**Restacked Rod Process wire**

Externally

Bruker-OST, 2019
Minimum Quench Energy Measurements

Schematics of the setup to measure MQE.

Pei Li, Xinchun Xu, and A. V. Zlobin, “Development and Study of Nb₃Sn Wires With High Specific Heat.” IEEE, VOL. 29, NO. 5, 2019
The initial temperature is 4.2 K and it is set as boundary temperature constraints:
- \( T(r,0) = 4.2 \text{ K} \)
- \( T(r,t) = 4.2 \text{ K} \) @boundary

Magnetic Field \( B=12\text{T} \)

An heat flux pulse of 200 µs is applied on the upper half arc (2D model) with unitary thickness.
By obtaining $I_c(12 \text{ T}, 4.2 \text{ K})$ using parameterization and solving for $T_c$ in $I_c(12 \text{ T}, T_c)$ the following critical temperatures:

<table>
<thead>
<tr>
<th>Current ratio $I/I_c$ @B=12 T</th>
<th>$T_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>6.3 K</td>
</tr>
<tr>
<td>0.4</td>
<td>5.3 K</td>
</tr>
<tr>
<td>0.6</td>
<td>4.8 K</td>
</tr>
<tr>
<td>0.8</td>
<td>4.4 K</td>
</tr>
</tbody>
</table>

Sensitivity of MQE from model was calculated for thermal conductivity and heat capacity variations of Nb$_3$Sn, Cu, Gd$_2$O$_3$, stycast and bronze.
MQE from model is lower than MQE from data since in the experiment 100% of the heat from the heater is assumed to go into the sample.
Is there an optimal thermal location for high-$C_p$ elements?
High-$C_p$ elements in the outermost row
Actual Bruker-OST Wire

High-$C_p$ elements in the innermost row
Virtual design
Simulation of Wire Drawing Step

5% true strain

Von Mises Stress, 5% strain

Work in progress, other material properties are being looked at to best represent drawing damage and confirm that for fabricability the location of the Gd$_2$O$_3$ tubes might be critical for success.
The FEM thermal models accurately reproduce relative behavior in Minimum Quench Energy between regular and high-$C_p$ wires.

They were also very useful in contrasting the intuitive thought that for maximum efficiency the $\text{Gd}_2\text{O}_3$ tubes have to be external to the superconducting elements.

This is good news since on the contrary there are indications that placing the $\text{Gd}_2\text{O}_3$ tubes externally hinders drawing.

FEM structural models have been developed to aid in the design of architectures that can be realized without drawing failure. Further analyses are required to find the right criteria.

More MQE measurements will be performed on both regular and high-$C_p$ wires.

Thank you for your attention.